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The excitation of ionic spectra by 100 kW high frequency pulses

By L. Minnhagen and L. Stigmark

With 7 figures in the text

Introduction

The application of modern high-frequency pulsing technique to the excitation of spectra has resulted in an installation which has already been described in a previous paper [1]. By means of a high-frequency generator, which was run intermittently with an output frequency of 9 megacycles per second, peak powers amounting to about 3 kilowatts were transferred to a discharge tube at an average power of about 500 watts. The repetition frequency was about 500 per sec, the duration of a pulse 400 microsecs approximately, and the anode voltage of the final amplifier tube 9 kilovolts or three times its normal value. Under these conditions the spectrum of singly ionized argon, A II, was produced with high intensity, great completeness and sharp lines. Parts of the A I and A III spectra also appeared but could easily be recognized as such by comparing the relative line intensities during pulse working of the oscillator with those obtained during continuous working.

The production of the complete A III and the A IV spectra as well as spectra of other doubly and trebly ionized elements requires still higher pulse powers. The experimental arrangement to generate large high-frequency pulse powers for this purpose and the study of the intensity variation of A II, A III and A IV with the peak power is the subject of the present investigation.

Experimental arrangement

In order to generate higher pulse powers than those delivered by the equipment previously described [1] we have employed a final power amplifier containing a water-cooled Philips triode *TBW* 12/25, this tube being chosen to suit the power supply at our disposal. The relatively large driving power necessary is taken from the old equipment, the output stage of which can be operated under moderate working conditions for this purpose. A schematic diagram of the new power amplifier is given n Fig. 1. The grid circuit is link-coupled to the driver via a coaxial cable, and it is built up symmetrically using a tapped coil and a split-stator tuning capacitor. In this way the necessary neutralization of the grid-plate capacitance can be easily achieved. The class C operation of the tube is secured by means of a fixed negative bias voltage amounting to 1000 volts delivered by a separate supply. The bias voltage

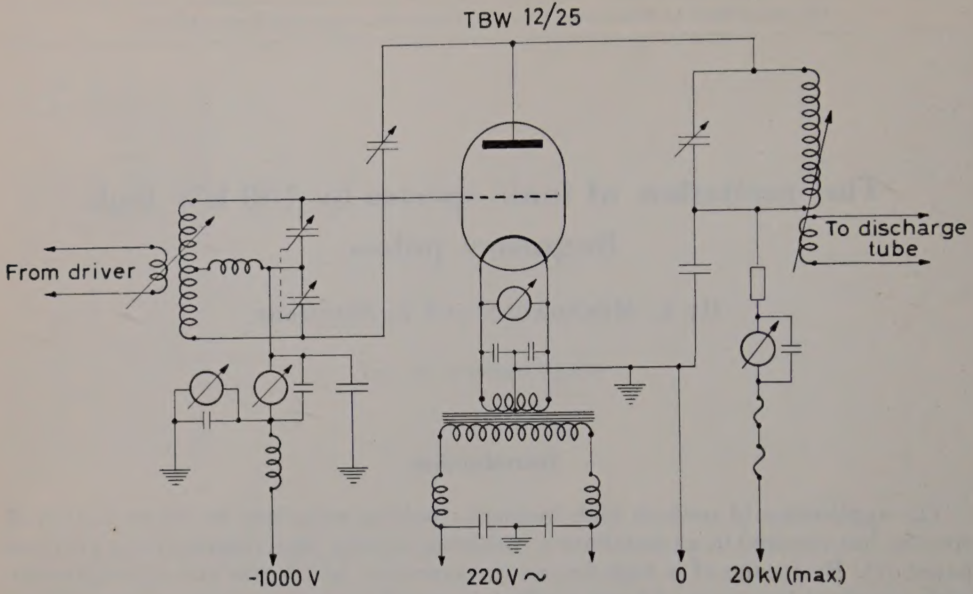

Fig. 1. Circuit diagram of the final power amplifier.

and the grid current are controlled by instruments as indicated. The anode tank circuit is made up of a coil of heavy copper tubing and a tubular tuning condenser with an inner tube 75 mm in diameter, coaxially adjustable in an outer tube of 130 mm diameter. The neutralizing condenser is constructed in the same manner in order to withstand the combined DC- and RF-voltages. The anode voltage of the power amplifier is taken from a separate, continuously adjustable, three-phase rectifier containing six high-vacuum diodes and adequate filtering. In the filter section the condensers have sufficient capacity to deliver the momentarily high anode current demanded during pulse operation of the final tube. The average anode current is controlled by an ammeter indicated in the schematic diagram, which also shows the necessary high-frequency chokes and by-pass condensers. To prevent high-frequency leakage through the cooling system of the final triode the water is led to the anode and back again through two plastic tubes, each having a length equal to a quarter of a wavelength.

The transfer of high-frequency power to the discharge tube is, of course, of decisive importance; a considerable time was devoted to this question in order to obtain optimum loading conditions. The best results were obtained with the coupling arrangement illustrated in Fig. 2. The high-frequency energy is taken from the tank circuit of the power amplifier by means of a coupling coil and via a coaxial conductor fed to a circuit consisting of a coil, surrounding the discharge tube, and a tuning capacitor. The discharge tube is similar to the one used in the previous investigation [1]. It is made of fused quartz with a cylindrical part 18 mm in diameter. Vitreosil windows, 40 mm in diameter, are fused to the widened ends, the total length of the tube being 20 cm. The surrounding coil is free-bearing and consists of 15 turns of silver-coated copper wire 4 mm in diameter and separated from the walls of the tube by 3 to 4 mm

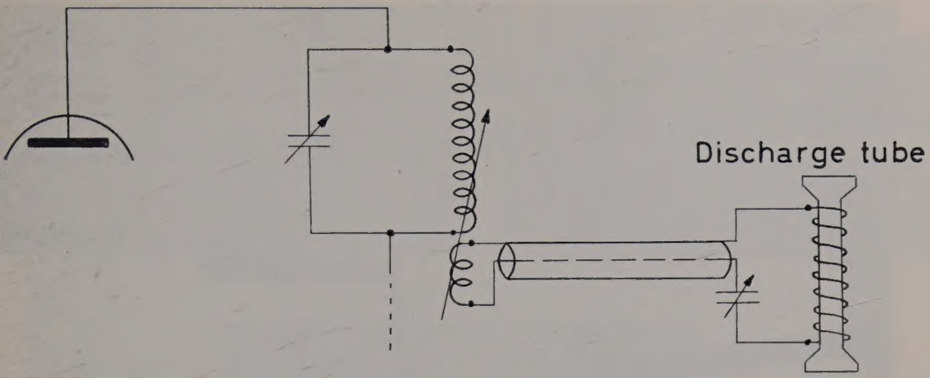

Fig. 2. The final resonance circuit and discharge tube.

of air. In order to avoid flash-over the coaxial conductor, having a length of 70 cm, has large dimensions, the outer and inner diameter amounting to 50 mm and 9 mm, respectively. For the same reason the tuning capacitors of the final circuit (two tubular capacitors in parallel) are of the same construction as those used for the final tank circuit and for neutralization.

The equipment is rack-mounted in three units. The first contains the driver which formed the whole high-frequency generator in the installation previously used. The new power amplifier is housed in another rack and the third rack contains the discharge tube circuit. The units are well shielded from each other to avoid unwanted coupling effects, which would give rise to instability. A photograph of the arrangement is reproduced in Fig. 3.

The tuning-up procedure of the driver is performed when the driver unit is running continuously. The tuning of the final power amplifier is performed during pulse working and is started by adjusting the split-stator condenser in the grid circuit for maximum grid current. The amount of driving power is controlled by the anode voltage of the final tube of the driver. The neutralizing condenser is adjusted with zero anode voltage on the power tube until no high-frequency power is observed in the tank circuit. Then the final tank circuit and the discharge tube circuit are resonated with reduced anode voltage. When the anode voltage is increased, the final circuit must be readjusted as the degree of excitation of the gas in the discharge tube affects the resonance setting. Optimum driving power for the power amplifier during pulse working was obtained by using an anode voltage on the *PB* 3/800 driver tube of 3.5 kilovolts.

The discharge tube is connected to a conventional gas circulating system. So far the installation has been run with argon or neon[1] in the discharge tube. The appropriate pressure of argon appears to be a few hundredths of a millimeter of mercury. The pulse frequency and the pulse duration of the oscillator are variable within wide limits, viz. 40–900 pulses per sec and 80–1000 μsecs, respectively. The oscillograms reproduced in Fig. 4 show the high-frequency pulses at three occasions picked up by means of a coil situated near the oscillator, which was run with approximately the same mean power. During pulse working it is possible to increase the anode voltage of the power amplifier tube to 20 kilovolts at a pulse length of 80 μsecs and

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[1] The experiments on neon will be described separately by B. Petersson.

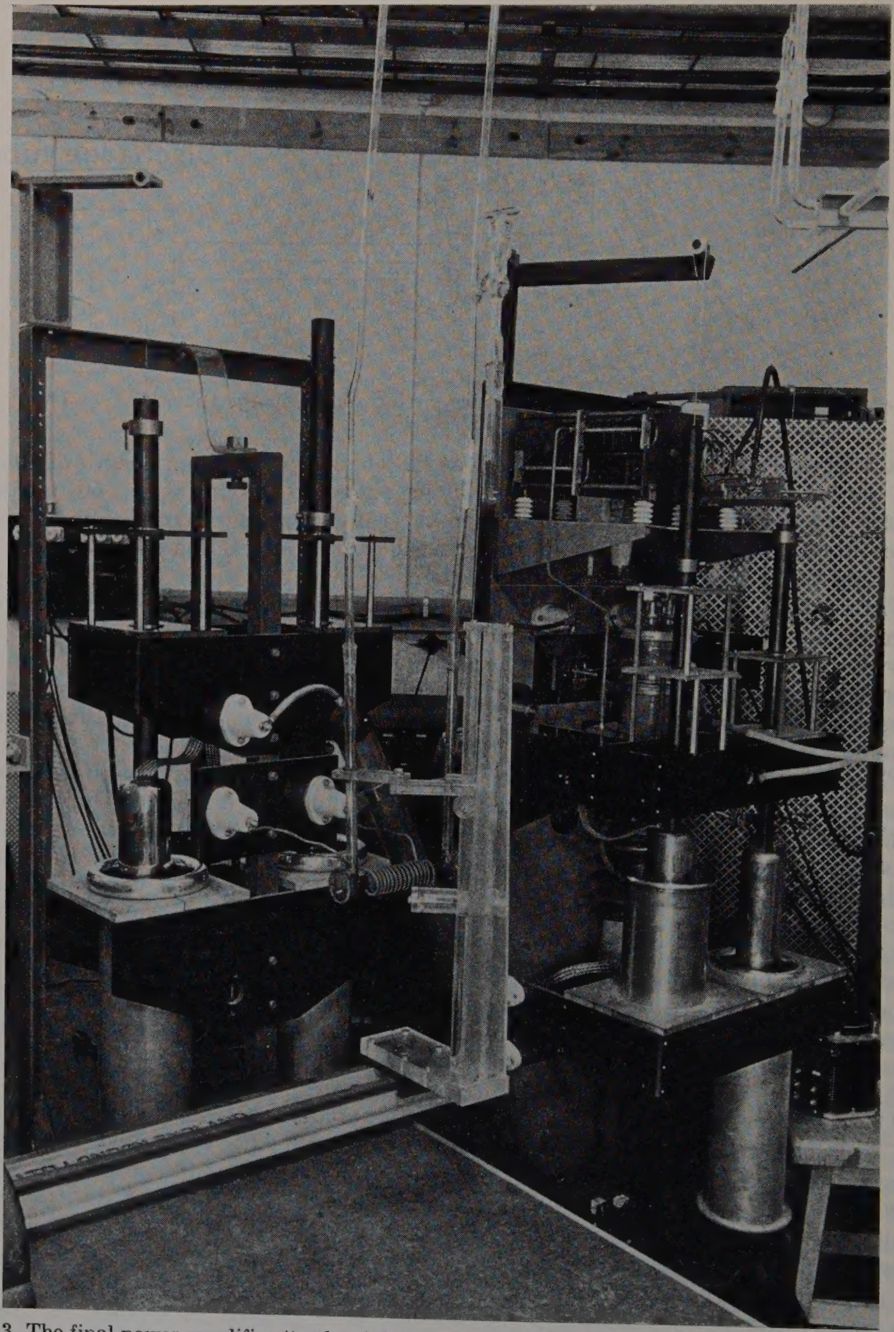


Fig. 3. The final power amplifier (to the right) and the final resonance circuit (to the left), shieldings removed. In the foreground the discharge tube in its perspex stand and behind it the coaxial conductor. The shielded rack to the right in the background contains the driver unit.

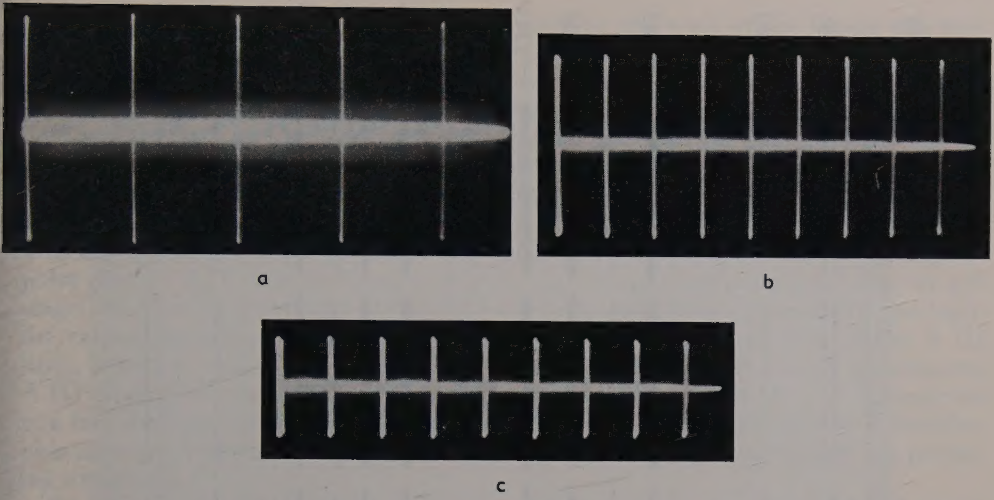


Fig. 4. Oscillograms showing the high-frequency pulses from the oscillator with the following pulse lengths and repetition frequencies: (*a*) 100 μsecs and 40 p/s, (*b*) 600 μsecs and 100 p/s, (*c*) 1000 μsecs and 100 p/s.

a repetition frequency of 40 pulses per sec. The average high-frequency power transferred to the discharge tube was about 400 watts, as estimated from the input power of the power amplifier and its efficiency, which is roughly known. From these data the momentary power during a pulse is calculated to be approximately 100 kilowatts.

Spectroscopic observations

Whilst, generally speaking, the total intensity of optical radiation is determined by the mean high-frequency power transferred to the discharge tube, the excitation characteristics, particularly the ionization stages attained, are determined by the peak power. In order to study, qualitatively, how the pulse power affects the excitation, the anode voltage of the power amplifier tube was increased by steps up to the highest value attainable with the present arrangement. Pulse length and pulse frequency were adjusted to maintain, approximately, the same mean power. The spectra were photographed with a Hilger E 478 spectrograph (quartz optics).

The spectral range λ 3240–3400 Å is illustrated in Fig. 5. The anode voltage was 5, 6, 8, 11, 15, and 20 kV, corresponding to approximately 5, 10, 15, 30, 50, and 100 kW pulse power. The exposure times were chosen so as to obtain the same photographic density of the A II lines. Therefore, the A II lines in Fig. 5 are recognized as those which maintain their density throughout the whole series of spectrograms. No differences in the intensity vs. peak power relation are noticed among the A II lines marked in the figure, which are, with one exception, $4p$–$4d$ transitions based either on ^3P or ^1D in A III.

The A III lines behave quite differently, gaining intensity with increasing peak power in a striking way. Thus, the $4s\,^5S_2 - 4p\,^5P_{3,2,1}$ lines λ 3285, 3301, and 3311 start with medium density on the lowest spectrogram but are quite overexposed on the top spectrogram taken with the highest pulse power. The lines 3336, 3344, and

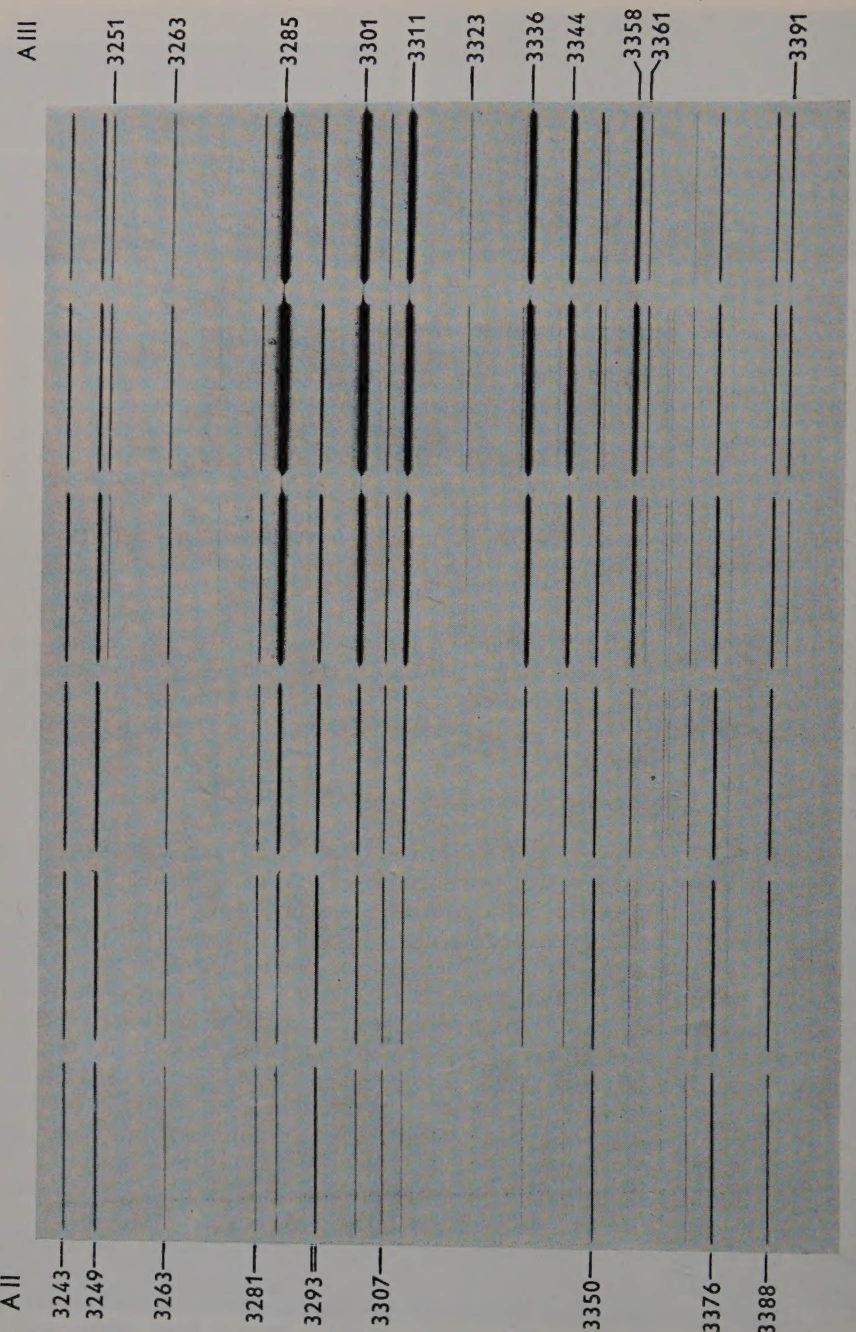


Fig. 5. Series of spectrograms in the range 3240–3400 Å showing the great enhancement of the A III spectrum in relation to the A II spectrum when the high-frequency peak power is increased from 5 to 100 kW approximately.

3358 Å, belonging to the $4s'^3D-4p'^3F$ transition, are weak at the lowest but very strong at the highest pulse power. The $3d''-4p''$ lines 3323 and 3391 Å are not observable on the first three spectrograms but have medium density on the spectrograms corresponding to the two highest peak powers.

Figs. 6*a* and *b* give a series of spectrograms obtained with approximately 15, 30, 50, and 100 kW peak power in the spectral range 2430–2800 Å. Also in this case the exposures are made so as to obtain approximately the same density for the A II lines. The last exposure, however, shows an A II intensity which is considerably smaller. This feature is connected to the development of the A IV spectrum at the highest pulse powers. A IV lines do not appear at all until the pulse power reaches the "50 kW stage" and are very strongly enhanced when the pulse power is increased to its highest value. The enhancement in this step is much stronger than that of the A III lines, as can be seen by comparing the A IV lines 2784 and 2788 Å with the adjacent A III lines 2783 and 2785 Å (Fig. 6*b*). The rapid enhancement of A IV corresponds to a fast reduction of the A II share of the total intensity. It would require a considerable increase of the exposure time to retain the A II density at the value of the preceding exposures.

To sum up, the alteration of the pulse power affects the line intensities of singly, doubly, and trebly ionized argon in quite different ways. The comparison of relative line intensities on spectrograms made with different pulse powers makes it possible to settle conclusively the ionization stages of the lines.

With the exception of some unclassified lines, the A IV lines seen in Figs. 6*a* and *b* belong to the $4s^4P-4p^4S, {}^4P, {}^4D, {}^2D$, $4s^2P-4p^2P$ and $4s'^2D-4p'^2D, {}^2F$ transitions [2].

The detailed identifications of the A II, A III, and A IV lines obtained by pulsed high-frequency excitation using the present and the previously described installations will be reported separately.

A few impurity lines appear on the spectrograms and show intensity variations which are characteristic of the extraneous elements and their ionization stages. Consequently, they can be distinguished from the argon lines. The C II lines 2509.136, 2511.736, 2512.045, 2746.378, and 2747.240 Å gain intensity with increasing pulse power, but not nearly so fast as the A III lines. Their behaviour lies between that of the A II and A III lines, as can be seen from the line group A III 2743.862, A II 2744.801, and C II 2746.378 and 2747.240 Å. Also C I 2478.564 differs somewhat from the A II lines. On spectrograms taken at lower pulse powers than those reproduced in Fig. 6*a* the intensity decrease with increasing pulse power is more obvious. Hg I 2536.519 is the only line which shows decreasing intensity throughout the whole series of increasing peak powers.

SUMMARY

An installation, previously described, used to excite spectra by high-frequency pulses has been developed and provided with a power amplifier containing a 25 kilowatt water-cooled triode. Pulse powers of up to approximately 100 kW are transferred to a discharge tube at a pulse duration of 80 μsecs and a repetition frequency of 40 pulses per sec. At the highest pulse powers spectra of singly, doubly, and trebly ionized argon are excited, whereas only the A II and A III spectra appear at lower peak powers, with a rapid increase of A III in relation to A II as the pulse power increases. Since the intensities of the A II, A III, and A IV lines are affected in different ways when the pulse power is changed, it is possible to settle conclusively the ionization stages to which the lines belong.

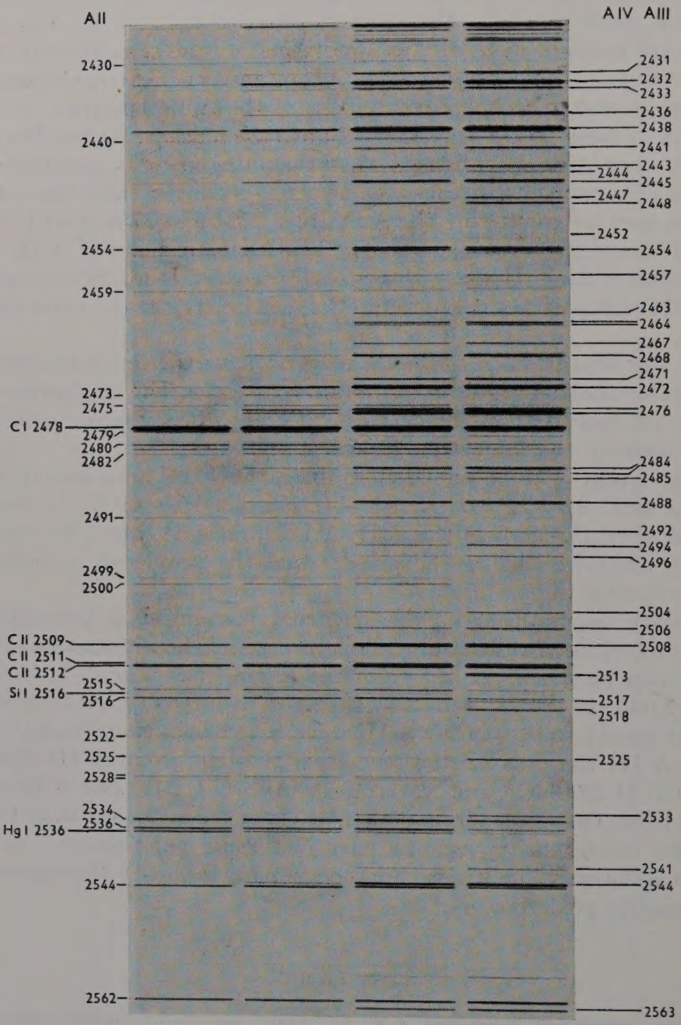
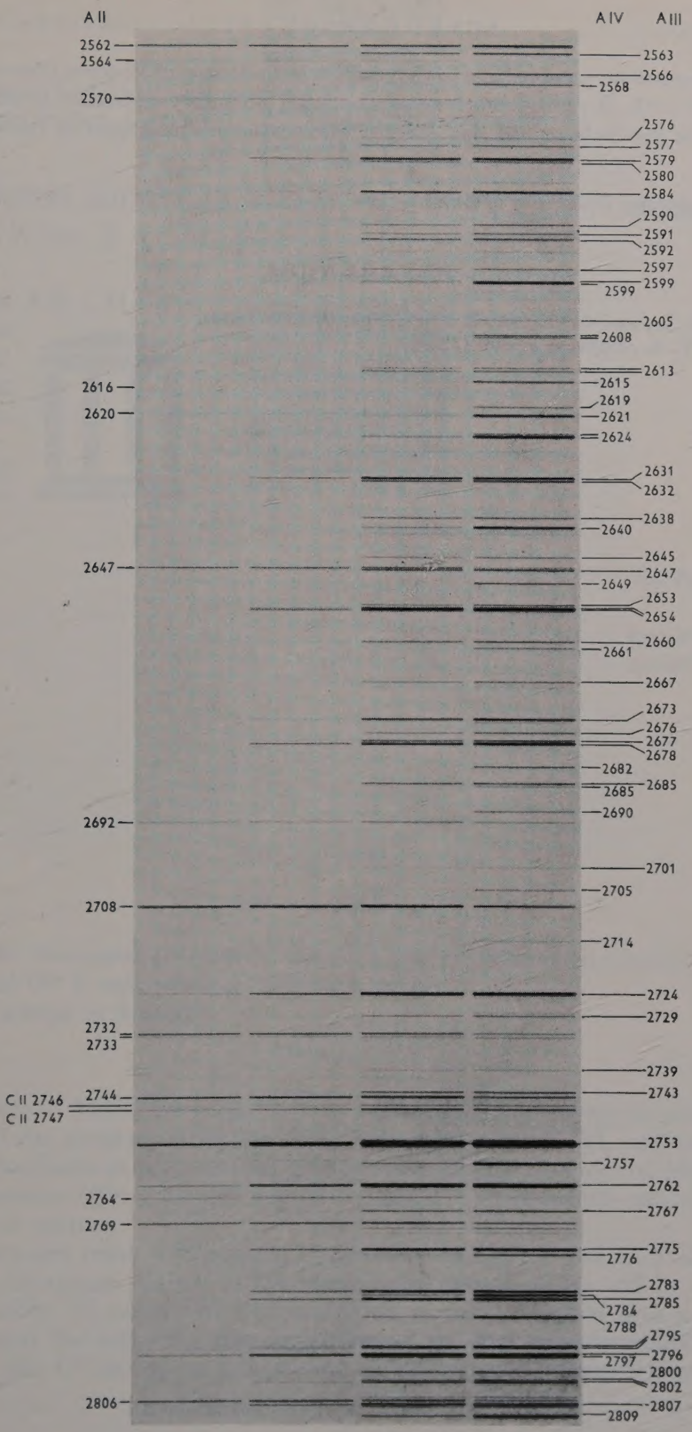


Fig. 6 a

Fig. 6. Series of spectrograms illustrating the entirely different intensity vs. peak power variation of A II, A III, and A IV lines up to approximately 100 kW peak power. Wavelength range: (*a*) 2430–2560 Å, (*b*) 2560–2800 Å.


A II
A IV
A III
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2564
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2647
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2708
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2733
C II 2746
2744
C II 2747
2764
2769
2806
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2802
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Fig. 6 b

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Physics Laboratory, University of Lund

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